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Physical, textural and sensory characteristics of reduced sucrose cakes, incorporated with clean-label sugar-replacing alternative ingredients

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Abstract

High levels of sucrose in foods present a great risk of obesity and type 2 diabetes. Therefore a low sucrose intake is strongly recommended. Sweet baked products incorporate high levels of sucrose. Sucrose in the original cake formulation was reduced and replaced with apple pomace, whey permeate, oligofructose, polydextrose. An acceptable sucrose reduction of between 21-27% was achieved. Cakes containing apple pomace had the lowest specific volume (1.8cm^3/g) and highest crumb firmness (8.60N) ($P<0.05$). Apple pomace and whey permeate had a significantly decreased L* values of the crust ($P<0.05$). Moisture content of the cake crumb was increased significantly with the addition of oligofructose, whey permeate and polydextrose. All treatments resulted in a significant increase of the water activity of the cake crumb compared to the control ($P<0.05$). Crumb cell structure was maintained as shown by 2-D and confocal imaging. Sensory trials revealed the reformulated cakes were acceptable to panellists.

Keywords: cake, cake structure, compositional analysis, physical properties, sensory evaluation, sugar reduction.

1. Introduction

There is an alarming increase in obesity and obesity related disease such as diabetes, heart disease and high blood pressure throughout the developing and developed world (Revels, Kumar & Assuli, 2017). Although risks of obesity can be increased due to genetic and environmental factors, the most common cause of obesity is an energy imbalance.

Sugar is high in calories and found in a wide variety of foods and beverages. Sugar reduction or removal in confectionary products is an important research objective for the food industry, considering negative press, consumer awareness around civilisation diseases and government strategies for sugar reduction in high sugar products (O'Sullivan, 2017). In Europe, some governments have implemented taxes and recommendations for food manufacturers and consumers for high sucrose products. For example, the Irish government introduced a sugar tax in 2018, which increased the price of beverages with a sugar content of greater than 5g/100ml of drink. In the UK, Public Health England has released an action plan to combat childhood obesity. This strategy aims to encourage the food industry to reduce the sucrose content of a variety of products by 20% by 2020. These initiatives are pressuring the food industry to produce reduced sucrose products, while consumers continue to demand high quality products.

Cakes are a high calorie food, containing a high sugar content. The quality of a cake is highly influenced by the quality and balance of ingredients. The primary ingredients of cake are; wheat flour, sugar, fat, egg and leavening agents. Due to the many functions of sucrose in cake products (Richardson, Tyuftin, Kilcawley, Gallagher, O'Sullivan & Kerry, 2018), the reduction of sucrose effects structure, colour, sweetness and shelf life of a cake.

Sucrose is hydroscopic and therefore binds to the water found in the cake batter. This results in an increase in the viscosity of the batter which is important as this helps to retain gas bubbles, increasing the final volume of the cake. As sugar binds with water, this prevents the full hydration of the gluten proteins (found in the flour), preventing the formation of a gluten network (Perego, Sordi, Guastalli & Converti, 2007). Sucrose increases the temperature of starch gelatinisation and egg protein denaturation, allowing gas bubbles to expand before the formation of the gel (Christ, Takeuchi & Cunha, 2005; Psimouli & Oreopoulou, 2012). Sucrose is important for the browning of the crust. Although sucrose is not a reducing sugar, when exposed to heat, it degrades to fructose and glucose. These monosaccharaides are reducing sugar and participate in Mallard browning. Sucrose also undergoes caramelization at high temperatures and produces a brown colour (Purlis, 2010).

The present study examines the use of clean label, novel sweetening ingredients (apple pomace, whey permeate, oligofructose, polydextrose) as possible sugar replacers.

Whey permeate is a by-product of cheese and whey protein manufacturing. When the curds and whey are separated in the cheese making process, the whey stream is filtered. Sprayed-dried whey permeate has a minimum of 85% lactose. Lactose is less sweet than sucrose, but it participates in Mallard browning and can crystallise on the surface of baked goods to form a crust and prevent the loss of moisture (Burrington, 2005). Due to the high lactose content, whey permeate is a possible sucrose replacer. However there no studies have been found where whey permeate was used in bakery products for sucrose reduction.

Apple pomace contains a high concentration of dietary fibre, manufactured as a by-product in the apple juice and cider industry. It has been used to enhance the fibre content of cakes and muffins (Masoodi, Sharma & Chauhan, 2002; Rupasinghe, Wang, Pitts & Astatkie, 2009; Struck, Gundel, Zahn & Rohm, 2016; Sudha, Baskaran & Leelavathi, 2007). It has been reported that the addition of apple pomace can increase the perceived sweetness of some baked goods (Rupasinghe et al., 2009).

Oligofructose is a dietary fibre, and formed by the partial enzymatic hydrolysis of inulin. In high concentrations (35%) it can be perceived as sweet as sucrose (Schaafsma & Slavin, 2015). Similar to sucrose, oligofructose has good stability at high temperature (Mensink, Frijlink, Maarschalk & Hinrichs, 2015), contributing to browning and demonstrates humectant properties. Partial replacement of sucrose in bakery products has been achieved in other studies (Handa, Goomer & Siddhu, 2012; Rossle, Ktenioudaki & Gallagher, 2011; Volpini-Rapina, Sokei & Conti-Silva, 2012). The addition of oligofructose and inulin in cakes has been shown to increase the browning and hardness properties of the cakes (Volpini-Rapina et al., 2012).

Polydextrose is manufactured from glucose, sorbitol and citric acid. It provides 1kcal/g of energy and is a dietary fibre. It is not sweet; however it increases the gelatinization temperature of starch and thickens cake batters. Polydextrose browns when heated and has been used to replace sucrose in cakes and muffin in other studies (Hicsasmaz, Yazgan, Bozoglu & Katnas, 2003; Martinez-Cervera, Sanz, Salvador & Fiszman, 2012; Ronda, Gomez, Blanco & Caballero, 2005). A reduction of sucrose was shown to result in a decreased volume and L* value of the crumb and the sensory panellists deemed the cakes as acceptable.

The objective of the present study was to investigate the effects of reducing sucrose in a cake formulation and include natural sugar alternatives.

2. Materials and methods

2.1 Ingredients

The ingredients used to prepare the cake batter were: plain wheat flour (Shackleton, Ireland), granulated sugar (Supervalu, purchased locally), fresh whole egg (purchased locally), water, margarine (stork soft blend for cakes, purchased locally), sodium bicarbonate (Royal, baking powder, purchased locally), Benco L91 (an oligofructose), apple pomace, whey permeate, polydextrose.

2.2 Batter and cake preparation

Before the current trial, a preliminary baking trial was conducted to establish a maximum level of sugar reduction of the cake formulation and sugar replacing ingredients.

A control formulation and five reduced sugar formulations were prepared as per Table 1, where 30% of the sugar was removed, and replaced by 5% replacer flour weight basis.

The cake batter was prepared in a Hobart PMFD158 (UK) mixer. Flour, sugar, egg, water margarine, sodium bicarbonate and sugar replacer were placed into the mixing bowl and mixed at a low speed (speed 1) for 30 seconds. The sides were scraped down, and the speed was increased (to speed 2) for 2 minutes. 80g of cake batter was placed into a pup loaf tin (80mm x 60mm x 40mm) and baked in a conventional oven (Macpan MDBt8, Thiene, Italy) preheated at 180˚C for 45 minutes. Cakes were stored at room temperature until cool and then packed into polypropylene bags and stored overnight to be analysed. All batches were prepared in triplicate. From each batch two cakes were analysed.

2.3 Cake analysis

2.3.1 Specific volume and density

The specific volume of each cake was determined as the ratio of the volume to its weight. Five whole cakes per batch per treatment were randomly chosen and used to calculate the specific volume using the TexVol instrument (BV-L370, Sweden). Samples were analysed on day of baking. The cake was placed into the volumeter vertically.

2.3.2 Crumb structure

The cake was sliced vertically in the centre, and a 1cm slice was cut from each half one day 1 post-baking. The sample was scanned by a C-Cell (Calibre Instruments Ltd, Warrington, UK) using the standard C-Cell software for data analysis. Slice area, height and width were measured, as well as crumb structure including; number of cells, number of holes, average cell diameter, wall thickness, distribution of cell diameters (coarse/fine clustering) and cell elongation characteristics. Measurements were performed in duplicate.

2.3.3 Crumb and crust colour

The L*, a* and b* values of crust and crumb of the cakes were determined using a Chroma meter CR-410 (Konica Minolta, UK), which had been calibrated using a standardised white tile. Ten readings were recorded on the surface (on the top region of the cake), and ten readings on the crumb colour of the cake for each treatments on day 1 post-baking.

2.3.4 Crumb hardness

Two slices (1cm) were cut vertically from the centre of the cake. Texture profile analysis was carried out using a TAXT2i Texture Analyser. The test was performed using each slice. Texture profile analysis was performed using a test speed of 1 mm/s with a strain of 40 % of the slice height, a trigger a force of 0.049 N was selected.

The parameters obtained were hardness (first force peak), chewiness, springiness, and cohesiveness. Measurements were performed in duplicate on each test day (day 1, 3, and 7 post baking).

2.3.5 Moisture

Crumb moisture was undertaken according to the AACC 44-15A method on days 1, 3 and 7 post-baking. The crust was removed from central two slices of the cake. The sample was cut into approximately 1cm^3 cubes and allowed to dry overnight at ambient temperature. The weight of the sample was recorded before and after drying (moisture 1). The dried sample was ground for 30 seconds using NutriBullet 600 (Australia) and sieved with an Endecott test sieve (1680 microns) to ensure crumbs were a uniform size. Three grams of the crumbed cake was placed into the Brabender oven (Mollelec Ltd, UK) at 130 C for 60 min. The weights after second drying were recorded (moisture 2).

Moisture content was calculated by the following equations:

Moisture 1: ((Sample before drying- Sample after drying)*100)/ Sample after drying

Moisture 2: Moisture % as measured using the Brabender

Total moisture: (Moisture 1 + Moisture 2) - (Moisture 1* Moisture 2)/100

2.3.6 Water activity

A section of the central region of the two centre slices was crumbed and the water activity of the cakes was determined by using an Aqua Lab Lite (Decagon Devices, WA, USA). Samples were carried out in duplicate on each test day (day 1, day 3 and day 7 post baking).

2.3.7 Confocal microscopy

Resin sections of the cake samples were placed on a microscope slide. One drop of 0.1% w/w ethanolic solution of fluorescein iso-thiocynate (FITC) was added to the surface of the sample. After 10 seconds, the FITC was drained off and replaced with one drop of 0.125% w/w aqueous solution of fluorescent brightener 28 (FB28), and one drop of Fast Green FCF (FG, 0.1% w/w aqueous solution) was added. Samples were rinsed with water. A coverslip was placed on top and the images were recorded in a Leica SP5 confocal scanning laser microscope (Leica Microsystems GmBH, Mannheim, Germany).

Readings were carried out at x 20 and x 63 oil immersion objective. Starch (green) were recorded at 488nm using an argon ion laser. Protein (bright red) was measured at 633nm using a helium-neon laser, and cellulosic materials (blue) were recorded at 405 nm using a blue diode laser.

2.3.8 Sensory evaluation

Sensory evaluation of the cakes were carried out by 20 semi-trained panellists on day 1 post-baking. Each panellist received half a slice of each cake (1 cm thickness). The samples were coded by three digit random numbers and were served at room temperature in a random order. Water was supplied as a palate cleanser between each sample.

A 9 point hedonic scale was used (9=like extremely; 8=like very much; 7=like moderately; 6=like slightly; 5 =neither like nor dislike; 4=dislike slightly; 3=dislike moderately; 2=dislike very much; 1=dislike extremely) to rate different parameters such as crust colour, overall appearance, texture while chewing, sweetness, aftertaste, overall acceptability.

2.3.9 Sugar analysis

Sugar analysis was performed by ion chromatography (AM/C/1014). Total sugar (sum of individual sugars), mono (fructose, galactose and glucose) and disaccharides (lactose, maltose and sucrose) were measured. Samples were analysed in duplicate.

2.3.10 Fibre analysis

Total fibre analysis was performed using the AOAC 985.29 1986 method. Soluble and insoluble fibre was analysed using the AOAC 991.43, 1994 method. Samples were analysed in duplicate.

2.4 Statistical analysis

All tests were replicated three times and mean values and standard deviation were calculated Statistical significance was considered at ($P \leq 0.05$). One-way ANOVA was performed on data using PASW Statistics 18 (SPSS Inc., Chicago, IL, USA). Where ANOVA indicated significant differences were present, a Tukey pairwise comparison of the means was conducted to identify where the sample difference occurred.

3. Results and Discussion

3.1 Physical characteristics

3.1.1 Specific volume

The volume of a cake is influenced by the incorporation of air into the batter, and the ability of the batter to entrap the gas. The presence of sugar has been found to have a significant impact on the volume of bakery products (Baeva, Terzieva & Panchev, 2003; De La Hera, Oliete & Gomez, 2013; Khouryieh, Aramouni & Herald, 2005).

The apple pomace-containing cake had a lower specific volume than the control ($P < 0.05$) (2.05 ±0.05 g/ml). All other reformulated cakes had a lower (but not significant) specific volume (Fig. 1). The presence of sugar influences bubble formation and expansion, therefore overall volume, as highlighted by this study.

In a study conducted by Sudha et al. (2007), involving fibre enrichment of cake using apple pomace, as the concentration of apple pomace increased there was a concurrent decrease in volume, from 850cm^3 (control) to 620 cm^3 as apple pomace increased to 30%.Interestingly, in their trial studying muffin formulations, Rupasinghe et al. (2009) demonstrated how adding apple skin powder (ASP) (4-8%) initially caused the volume of the muffins to increase, however higher concentrations (32%) of ASP resulted in a volume decrease. The authors concluded that this was due to the increase in water binding capacity of the fibres in apple pomace. Masoodi et al. (2002) demonstrated how the particle size (30, 50, 60 mesh sieve) of the apple pomace effected on cake volume. There was a significant decrease in the volume of the cakes containing an inclusion level of 15%, the volume decreased from 961.6 cm^3 (the volume of the control) to 886.6 cm^3.

During baking, the volume of a cake can increase by 50-80% (Lostie, Peczalski, Andrieu & Laurent, 2002). The presence of apple pomace has been shown to increase the water absorption of cake batter (Masoodi et al., 2002; Sudha et al., 2007) due to the high fibre content, this influencing the viscosity, elasticity, gluten network and subsequently the volume of the batter.

When cake batter is heated during baking, the air bubbles begin to expand. The expansion of gas when exposed to heat is responsible for 10-15% of the air bubble inflation in the cake batter. The additional expansion of the bubble is due to the vaporisation of the batter components at the interface of the cell (Zhou & Hui, 2014). Lostie et al. (2002) concluded from their study concerning heat transfer in sponge cake batter, water vapour was the most predominant gas for air bubble expansion in a sponge cake. In the present study, was possible the fibres in the apple pomace bound to the water, which usually evaporates from the batter.

This could have prevented the build-up of vapour pressure in the air bubble; therefore the bubble could not expand fully, resulting in a decreased volume of the cake.

3.1.2 Colour

Crust and crumb colour of any baked product, especially cakes, is important for overall acceptability. Colour was measured on the Minolta scale, using three axes. L* indicates the brightness of the sample, where a low number (0-50) indicates a dark coloured sample, and a high number (51-100) indicates a light coloured sample. The a* value represents the red or the green undertone of a sample, where a positive value indicates more of a red colour, and a negative value indicates more of a green colour. The b* value refers to the blueness or the yellowness of the sample, where a positive value represents a yellow hue, and a negative value represents a blue hue.

It can be seen in Fig. 2, the addition of apple pomace and whey permeate resulted in a significant decrease in the L* value of the crust compared to the control ($P < 0.05$), indicating a darker external appearance.

A darker crust has been found in other studies, as well as a crumb colour change from a creamish yellow to a darker brown, following the inclusion of alternative sugar replacers. Studies have shown how the addition of apple skin powder decreased in the L* value of the muffins, and adding fibres to breads increased in greyness and darkness in crumb colour (Rupasinghe et al., 2009). Likewise Struck et al. (2016) recorded a decrease in the L* values of cakes containing 30-100% apple fibre.

The crust and crumb undertones are represented by a* (red hue) and b* (blue hue) value. The addition of whey permeate in the formulation resulted in an increase in a* values (17.6 ±0.3) of the crust compared to the control cake (14.9±1.2), indicating an increase in a red undertone and a significant decrease in b* in both crumb compared to the control (37.6±1.7 and 39.7±0.9 respectively) ($P < 0.05$), possibly due to Mallard browning. The apple pomace inclusions significantly increased the in a* value of the crumb, and decreased the b* value of the crust compared to the control (-0.1±0.2 & 3.4±0.2, 39.7±0.9 & 35, 9±0.5) ($P < 0.05$).

It was noted in other studies where bakery formulations contained inclusions of fruit and vegetable fibres (Rupasinghe et al., 2009), the lightness of the samples decreased, resulting in a darker crumb colour and increasing the greyness of the sample. It is also possible the difference in colour was due to ß-glucan content. Apples are a source of ß-glucan (Jozinovic et al., 2016), which is known to effect the structure and colour of a baked product (Foschia, Peressini, Sensidoni & Brennan, 2013). The apple pomace was produced from pulp and skins of apples; it was not surprising the pomace was a dark orange colour. The darker colour of the pomace coupled with the presence of ß-glucan could have resulted in the difference in colour of the apple pomace-containing sample and the control.

The whey permeate-containing cake had an increased a* value and a decreased L* value on the crust. As these colour differences were only found on the crust, this may give evidence the difference in colour is due to Maillard browning. Whey permeate contains high levels of lactose, which participates in Maillard browning (Al-Eid, Al-Neshawy & Ahmad, 1999). Non-enzymatic browning has been seen to decrease L* value in bakery products, and also to increase the red undertone (Rothschild et al., 2015), as also seen in this study.

3.2 Texture/ staling properties

Cakes are prone to staling, due to the airy structure of the product, which allows water to migrate from the crumb to the crust, and external environment. This leads to an increase in crumbliness and deterioration of the overall cake texture.

3.2.1 Crumb hardness

The hardness of a food is defined as the peak force of the first compression of the TPA profile. Hardness evaluates the ease of the first bite of a food product.

The results from this study are represented in Fig. 3. Texture profile analysis was conducted on fresh samples (day 1 post baking) and throughout storage (day 3 post-baking and day 7 post-baking). All of the treatments showed a significant increase in crumb hardness during storage ($P < 0.05$). Cakes containing apple pomace had a significantly harder crumb than the control formulation on day 1 ($P < 0.05$).

Soluble fibre (which are the fibres found in apple pomace and oligofructose) has been shown to impair textural characteristics and increase hardness of cakes and muffins. In other studies (Rupasinghe et al., 2009; Sudha et al., 2007) the inclusion of apple fibres increased the firm texture of cakes and muffins. It was revealed that the formulations containing high concentrations of apple pomace did not rise well during baking and were more dense than control formulation. It was hypothesised by the authors this may had been related to the high water binging capacity of apple fibres, resulting in a firmer cake.

The cake containing 70% sucrose had the largest increase in hardness from day 1 to day 3, and a similarly large increase from day 3 to day 7 compared to all other samples. Although the cake containing 70% sucrose was not significantly harder than the control formulation on day 1, it was not surprising to see a dramatic increase in hardness as days increased. Sugar is a humectant, which can reduce water migration from crumb to crust. Therefore, a decrease in sucrose may result in an increase in water migration causing a harder crumb.

3.2.2 Crumb moisture

Moisture content and crumb hardness have an inverse relationship. The moisture content of a food product influences textural attributes of the product. Sucrose is hygroscopic and a humecent, which binds to moisture, thus decreasing the rate of this migration. This highly influences the staling and therefore the shelf life of cake.

The results from this study are represented in Fig. 4. Moisture content was measured using a two stage drying process (AACC 44-15A).

The cakes containing polydextrose had significantly greater moisture contents than the control formulation on each test day ($P < 0.05$). Cakes containing whey permeate and oligofructose had significantly greater moisture content on day 3 and 7. The cakes containing whey permeate, oligofructose and polydextrose had the greatest percentage moisture loss from day 1 to day 7 (6.30%, 6.02%, and 6.87% respectively). However at the end of the testing period, the crumb moisture content of the cakes containing whey permeate, oligofructose and polydextrose were significantly higher than that of the control.

Jooyandeh, Minhas and Kaur (2009) demonstrated how the use of whey permeate (WP) in bread resulted in a significant increase the moisture content of bread compared to the control. Water was replaced in the bread formulation with a solution containing 0%-100% WP and water. There was an increase in crumb moisture content from 33.0 ± 0.93% (control) to 37.2 ± 0.57% (100% replacement). The authors hypothesised this increase in moisture was a result of the high water holding capacity of whey proteins (Jooyandeh et al., 2009). Although whey permeate contains a low percentage of whey proteins (maximum 3%), the concentration may still have increased the moisture content of the cake.

Praznik, Cieslik and Filipiak-Florkiewicz (2002) observed a significant increase in the moisture content of bread with inclusions of 8% and 10% oligofructose compared to the control bread. This addition of 8% and 10% oligofructose resulted in the moisture content of the control to increase from 43.7 ± 0.2% (control) to 58.5 ± 0.3% and 57.3 ± 0.3% respectively. The significantly greater moisture content of cakes containing oligofructose and polydextrose may be due to the presence of soluble fibres in the ingredients, which have higher water holding capacities.

3.2.3 Crumb water activity

Water activity (a_w) is an important factor for the safety and textural attributes of a food. Water activity is influenced by water migration, which influences the texture of the food system. When the food has an a_w greater than the relative humidity of the environment (e.g. cake), moisture migrates from the internal structure to the surroundings, resulting in staling. The water activity of each treatment was recorded on day 1, day 3 and day 7 post baking using the Aqualab water activity meter. The results are represented in the Fig 5.

Overall, the control formulation had the lowest a_w (0.891 ± 0.038). Sugar is hygroscopic and therefore this possibly explains why the control formulation had the lowest a_w when compared to the reduced sugar formulations. The a_w of the cakes containing 70% sucrose, oligofructose and polydextrose were significantly greater than the control formulation on all test days. Apple pomace, whey permeate-containing cakes had greater a_w on day 1 and day 3 post baking ($P < 0.05$).

The control cakes had the greatest decrease in a_w from day 1 to day 7 (0.919 ± 0.01 on day 1 to 0.849 ± 0.03), whereas the oligofructose containing cake maintained a high a_w from the first sample day to the last (0.931 ± 0.01 to 0.878 ± 0.03).

In a study conducted by Psimouli et al. (2012) where sucrose was completely replaced in a cake formulation. The authors revealed the addition of polydextrose and oligofructose resulted in a significant increase in a_w. The high concentration of fibres in polydextrose and oligofructose may have caused the increase in a_w.

3.3 Crumb 2-D Imaging

3.3.1 C-Cell Imaging

Image analysis was used to examine the crumb grain of each formulation. The C-Cell is an image analysis system which evaluates the internal structure of a bakery product.

In this study, two central cake slices from each formulation were analysed. Most interesting results were related to the cells and holes within the slices. The area of cells and holes were calculated by the total number of pixels within a cell or hole, volume was based on the degree of shadow and area of a cell or hole in the crumb. A hole is defined as a cell which is greater than the value of three times one standard deviation.

The number of individual cells was recorded within the slice of each cake. From Table 2, it can be seen the control cake had the greatest number of cells. A higher number of cells can indicate a finer structure and a decrease in cell number can indicate a coarser crumb. There was no significant difference between the control formulation and the reformulated cakes.

The C-Cell classifies large cells as 'holes'. The volume of holes refers to the total number of pixels in each hole. Baked goods with a large amount of holes are not desirable as large gas pockets negatively impact the sensory and shelf life of the product. An increase in hole volume could indicate instability in bubble growth during baking, resulting in the coalescence of smaller bubbles. However, no significant difference where found between the treatments and the control formulation in this study.

3.3.2 Confocal microscopy

Confocal microscopy was used to study the internal microstructure in the cake. Images were recorded using a Leica SP5 confocal scanning laser microscope. The images were read at three different wavelengths (405nm, 488nm and 633nm), with three types of lasers (argon, blue diode, helium neon).

Sugar has a major effect on the temperature of gelatinization of starch and also prevents the formation of a gluten network in cakes, therefore the reduction the sugar concentration can result in a change in structure. Although there was a sugar reduction of over 20% in the reformulated cakes, there was no significant alteration in the microstructure of the formulation. Alternatively, the sugars and/or fibres found in the sugar replacers may have helped to maintain the structure of the cake (for example, polydextrose is known to increase the temperature of gelatinization in starch).

3.4 Sensory analysis

Taste and texture are some of the most important attributes when developing a novel product. The panellists were asked to evaluate the cake formulation based on colour of crumb, overall appearance, texture while chewing, flavour, sweetness, aftertaste and overall appearance, rated on a hedonic scale (1 extremely dislike, 9 extremely like). The results are displayed on Fig 7.

Overall, the control formulation was favoured and received the highest preference scores in many of the attributes (texture while chewing, flavour, aftertaste, sweetness and overall acceptance). The apple pomace-containing cake was ranked lowest and classified as ‘dislike slightly’ (4.2). The panellists found the formulation containing apple pomace was the least favoured with regards to colour, texture while chewing, flavour, aftertaste and overall acceptance compared to the control ($P < 0.05$). Both apple pomace and oligofructose were significantly less favoured than the control in regards to texture while chewing. Importantly, there was no significant difference in sweetness perceived between any treatment and the control.

As previously discussed, the addition of apple pomace had a significant impact on many baking properties of the cake. Cakes containing apple pomace had a darker (reduced L* value) crumb and crust and firmer a crumb. In contrast, other studies (Rupasinghe et al., 2009; Sudha et al., 2007), cakes containing up to 20% AP were found to be acceptable to the panellists.

In another study, there was a significant decrease in scores for crumb colour in cakes containing apple pomace, as the crumb changed creamish to a darker brown colour according to a sensory evaluation conducted by Sudha et al. (2007). The authors also found that the cake containing 20% apple pomace was still acceptable to the panel. However, apple pomace was not used as a sugar replacer in either of these studies, which may possibly explain how the authors were able to enrich the cake with apple pomace at such high concentrations without impacting the attributes of the cake negatively.

3.5 Composition analysis

3.5.1 Sugar analysis

Total sugar (sum of individual sugars), mono (fructose, galactose and glucose) and disaccharides (lactose, maltose and sucrose) were measured and results are displayed in Table 3.

The reformulated cakes had a total sugar reduction between 21.5% (whey permeate) and 27.6% (oligofructose). European regulation (European Commission, 2006) state for a food product to be classified as 'reduced' in a nutrient, there must be a minimum decrease of 30% however, a reduction of over 20% is a substantive decrease in sugar.

As expected, a notable increase in fructose was observed from the cake containing apple pomace. The cakes containing apple pomace also contained higher concentrations of glucose and maltose. Apples are a known source of fructose (Noro, Takahashi, Ichita, Muranaka & Kato, 2006; Tavera-Quiroz, Urriza, Pinotti & Bertola, 2014) and glucose (Sato, Vieira, Zardo, Falcao, Nogueira & Wosiacki, 2010).

The cakes containing whey permeate contained the highest quantity of lactose and galactose compared to all the other reformulated cake. Whey permeate (as previously discussed) is primarily comprised of lactose (65%- 85%) (Burrington, 2005). Lactose is a disaccharide which consists of galactose and glucose. This explained the increase in lactose and galactose concentration of cakes containing whey permeate.

Cakes containing oligofructose and polydextrose had approximately 28% decrease in sucrose, and a decrease in total sugars by an approximately 27%. Oligofructose and polydextrose are comprised of predominantly fibres, which may have been the reason why there was less sucrose and therefore total sugars found in the reformulated cakes.

3.5.2 Fibre analysis

Soluble and insoluble fibre was conducted using the AOAC 991.43 1994 method and total fibre was determined by the AOAC 985.29 1986 method. Results are shown in Table 4. The addition of apple pomace doubled the soluble fibre content of the reformulated cakes. This resulted in an over 60% increase of total fibres compared to the control. Other studies (de Toledo, Nunes, da Silva, Spoto & Canniatti-Brazaca, 2017; Sudha et al., 2007) revealed an increase in soluble and total fibre due to the addition of apple pomace. The soluble fibres increased by more than double in the polydextrose and oligofructose-containing cakes. The increase in concentration of soluble fibres in the oligofructose and polydextrose was as expected, as they are a known source of soluble fibre.

4. Conclusion

A sugar reduction of between 21-27% was achieved in the cake formulations. The use of polydextrose, whey permeate and oligofructose as sweetening ingredients produced a cakes with similar physiochemical properties, crumb hardness, moisture and a_w as the control cake. Crumb cell structure was maintained for all cakes: there was no significant difference between the control formulation and the reduced sugar cakes as shown by 2-D. It is therefore possible to reduce the sucrose concentration in a cake formulation without dramatically altering the taste, staling profile and overall structure of the cake. Cakes containing apple pomace had the lowest specific volume, highest crumb firmness and scored the lowest in overall acceptability by the sensory panel.

5. Acknowledgments

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Declarations of interest: none

Industrial relevance

Public awareness about the health risks of diets high in sugar have increased dramatically for the last number of years. Governmental and professional groups have recommended sucrose to be reduced in certain food products; therefore the food industry is now seeking ways to reduce the sugar by substituting other materials. However, most people enjoy the taste and texture of high sugar foods, and may not want to give them up. As sugar is present in such significant amounts in cakes, altering the level used will greatly affect dough consistency and final product characteristics. Efforts have made over the last number of years to explore alternative sweetening ingredients including bulk sweeteners (polyols) and high intensity sweeteners as sucrose replacers (Di Monaco et al., 2018). However, recent consumer trends indicate a movement towards a 'clean label'. Clean label implies a food a low number of ingredients and ingredients with names with the consumer can understand (Skelke, 2018). Polyols and high intensity artificial sweeteners are not considered to be a 'clean label' ingredient, and therefore alternatives must be reviewed. This study investigates the use of clean label sweetening ingredients. Apple pomace and whey permeate are by-products of the juice and dairy industry. Both polydextrose and oligofructose can be classified as dietary fibres, and also provide other functional properties to the cake.

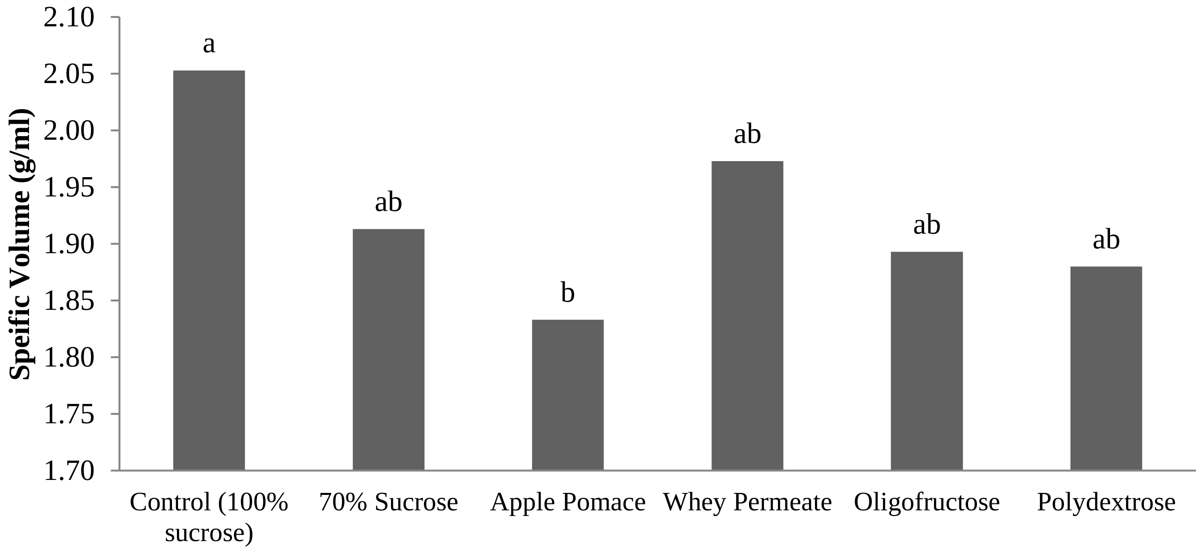


FIG 1. Specific volume of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose).Values are labelled with superscript (a-b) are significantly different (P < 0.05).

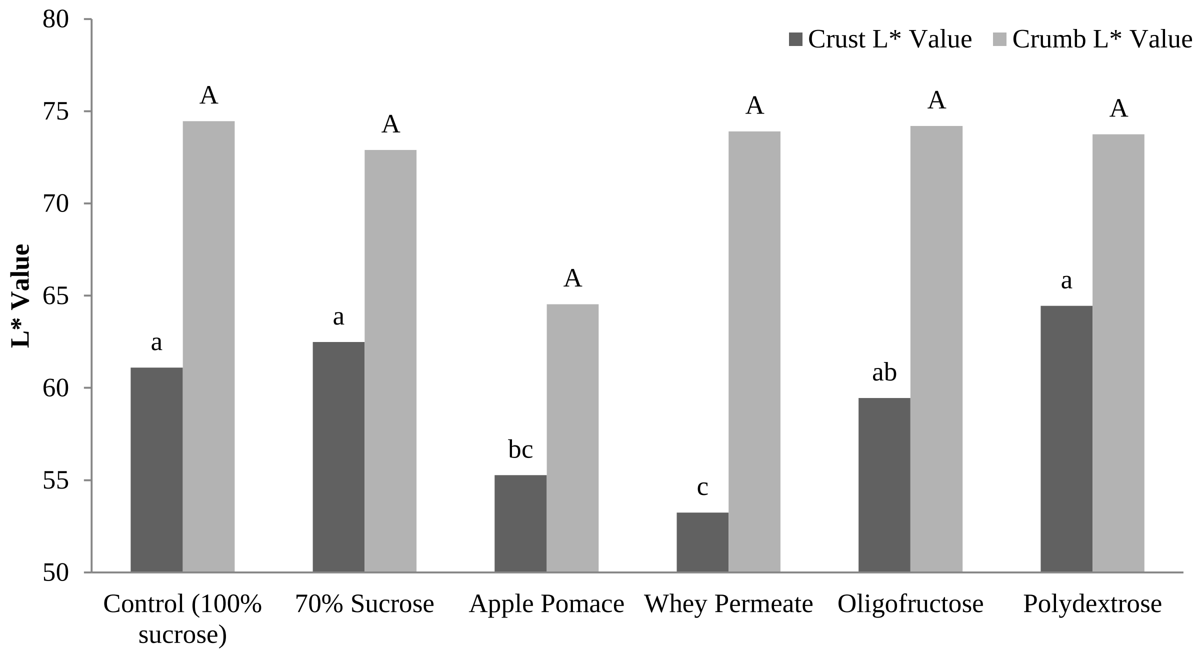


FIG. 2 Lightness (L*) values of cake crust and crumb of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose). Values are labelled with superscript (a-b and A-B) in the same subset are significantly different (P < 0.05).

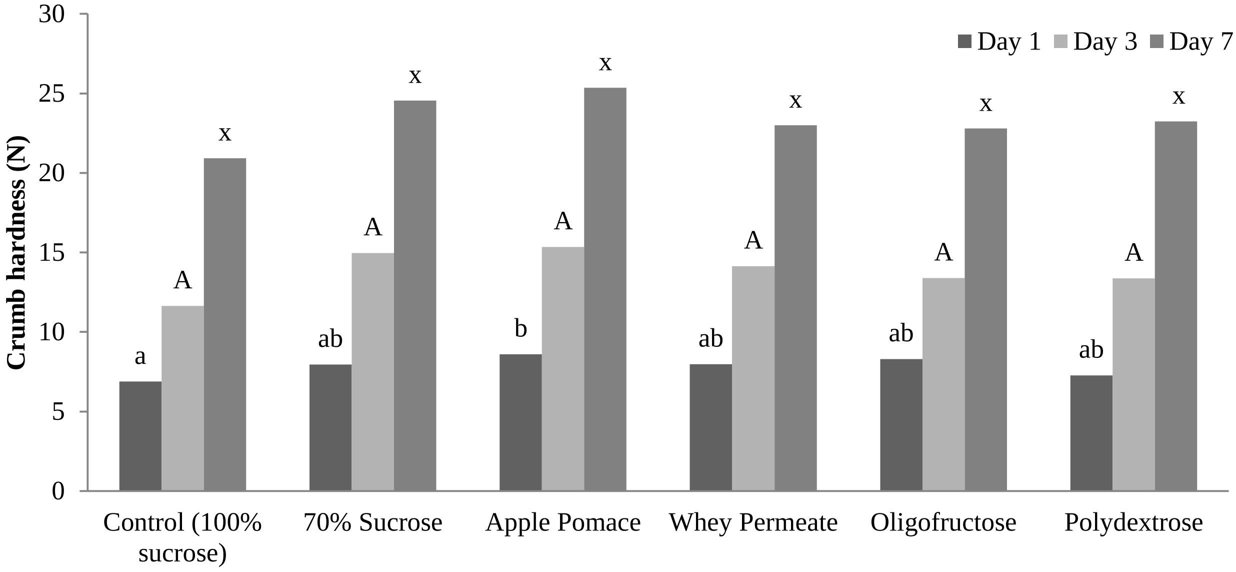


FIG. 3 Crumb hardness of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose) on days 1, 3 and 7 post baking. Values are labelled with different superscripts in the same subset are significantly different (P < 0.05).

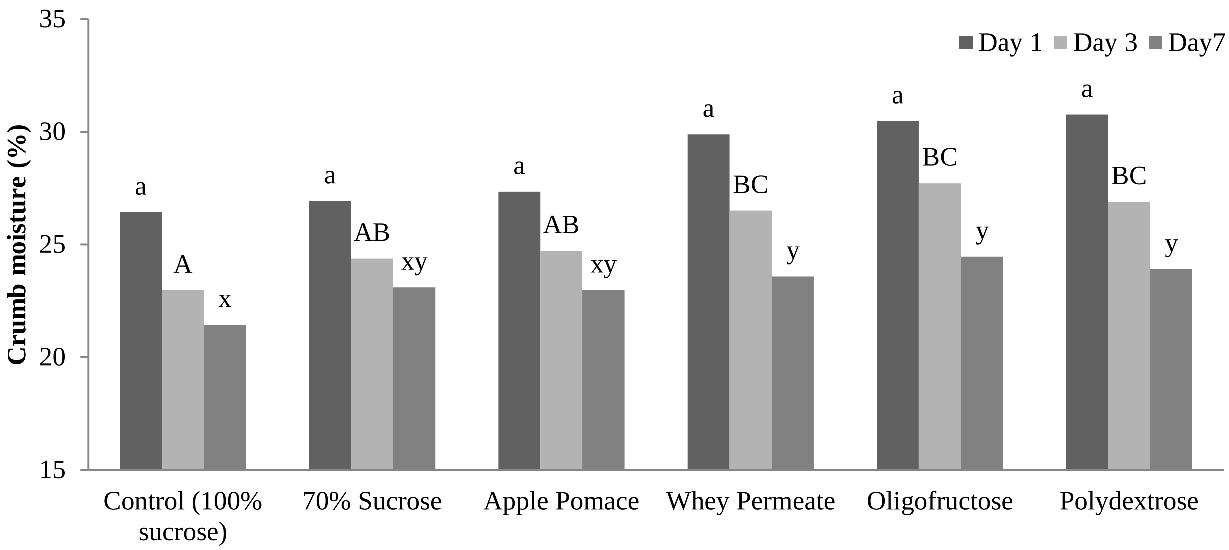


FIG. 4 Crumb moisture of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose) on day 1, day 3 and day 7 post baking. Values are labelled with superscript (a-b, A-B, x-y) in the same subset are significantly different (P < 0.05).

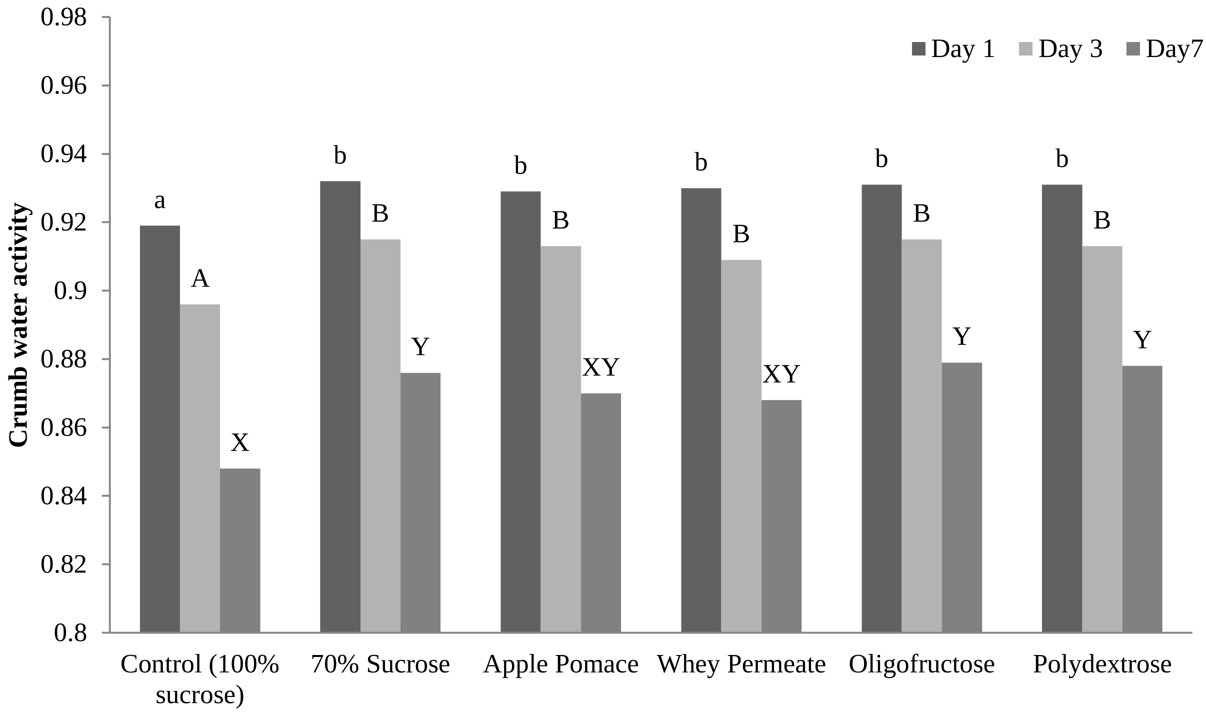


FIG. 5 Crumb water activity of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose) on day 1, day 3 and day 7 post-baking. Values are labelled with superscript (a-b, A-B, X-Y) in the same subset are significantly different (P < 0.05).

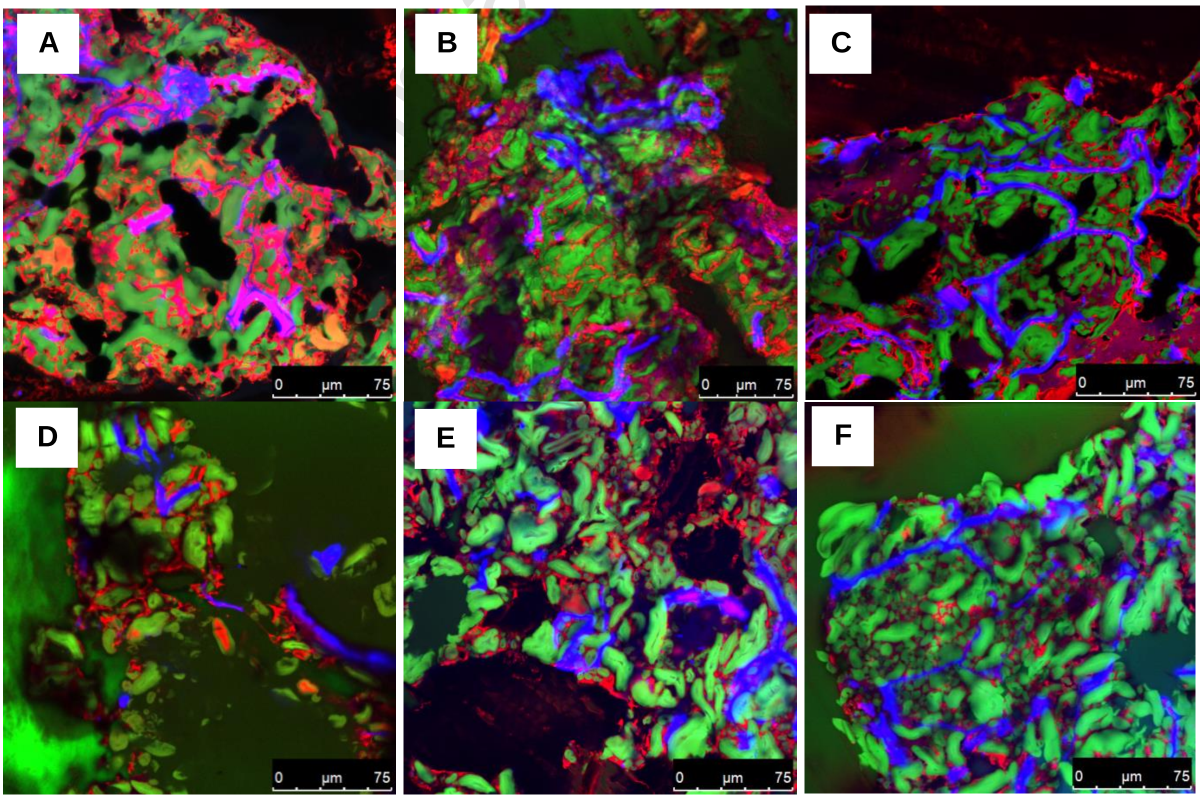


FIG 6: Confocal microscopy of reformulated cakes (A= control, B= 70% sucrose, C= apple pomace, D= whey permeate, E= oligofructose, F= polydextrose), magnification = 75 µm.

In the above figure, there are three structures observed in each image. The green structures correspond to starch (found in the flour), the bright red sections correspond to protein, (found in the egg and flour), and the blue corresponds to the cellulose materials (from the flour).

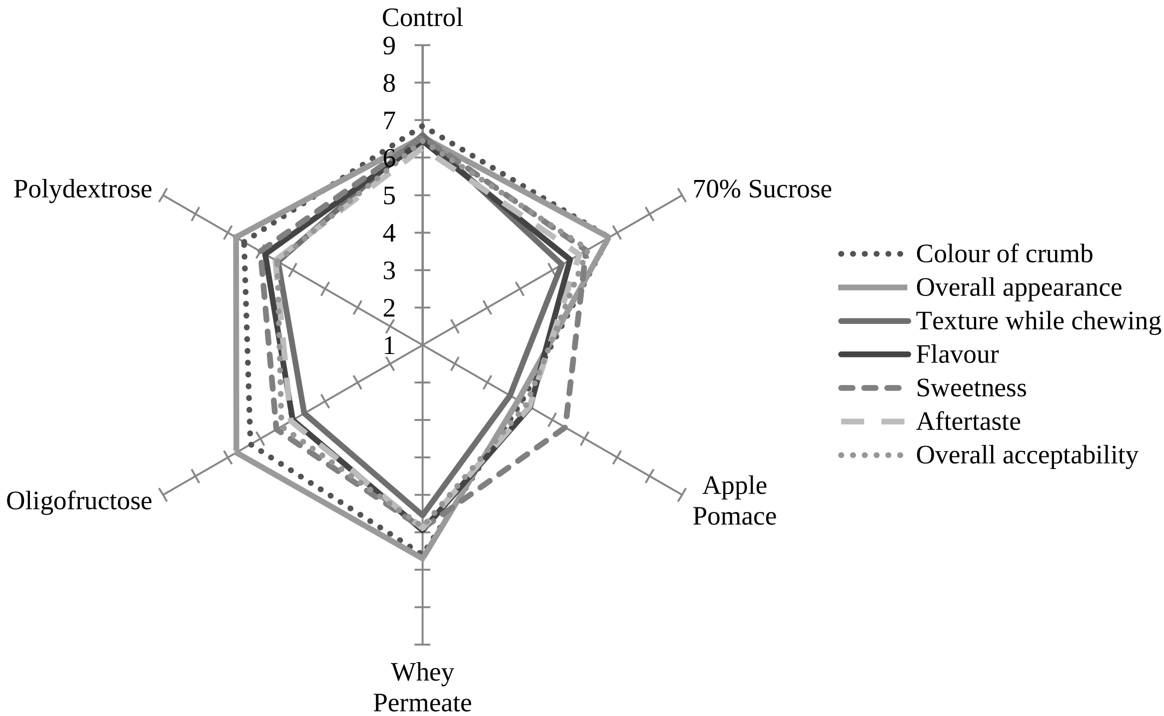


FIG. 7 Sensory evaluation of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose) scored on a 1–9 hedonic scale.

Table 1: Control, reduced and reformulated formulations, % of total batter weight.

	Control cake (%)	Reduced sugar cake (%)	Reformulated cakes (%)
Flour	35.5	37.7	37.0
Fat	16.0	17.0	16.6
Egg	16.0	17.0	16.6
Water	12.4	13.2	12.9
Baking powder	0.7	0.8	0.7
Sugar	19.5	14.5	14.2
Sugar replacer	-	-	1.9

Table. 2 Crumb structure of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose).

Treatment	Number of Cells	Volume of holes
Control	1760.17 ± 61.82^{a}	32.79 ± 9.55^{A}
70% Sucrose	1670.75 ± 83.74^{a}	38.29 ± 9.37^{A}
Apple Pomace	1656.33 ± 104.81^{a}	41.245 ± 1.48^{A}
Whey Permeate	1667.42 ± 44.95^{a}	29.73 ± 4.59^{A}
Oligofructose	1735.67 ± 25.77^{a}	26.65 ± 11.52^{A}
Polydextrose	1724.25 ± 61.38^{a}	45.90 ± 7.53^{A}

Values are labelled with superscript (a-b and A-B) in the same subset are significantly different ($P < 0.05$).

Table 3: Sugar content of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose) based on g sugar/ 100g of cake.

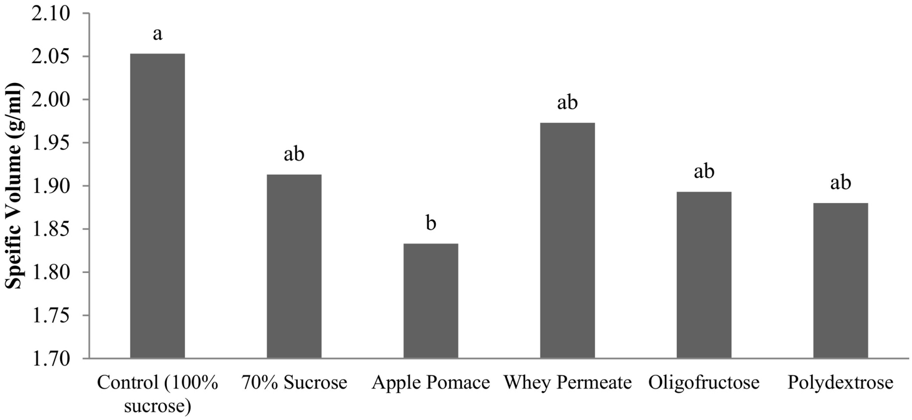
Treatment	Fructose	Galactose	Glucose	Lactose	Maltose	Sucrose	Total Sugars
Control	0.03	< 0.01	0.06	< 0.01	0.09	22.98	23.18
70% Sucrose	0.03	< 0.01	0.06	< 0.01	0.16	17.27	17.54
Apple pomace	0.60	< 0.01	0.26	< 0.01	0.24	16.64	17.76
Whey permeate	0.04	0.04	0.08	1.27	0.17	16.64	18.24
Oligofructose	0.08	< 0.01	0.07	< 0.01	0.16	16.49	16.91
Polydextrose	0.08	< 0.01	0.08	< 0.01	0.16	16.58	16.92

Table 4: Fibre content of control (100% sucrose) and reduced sucrose cakes with the addition of different sucrose replacers (apple pomace, whey permeate, oligofructose and polydextrose) based on g fibre/ 100g of cake.

Treatment	Soluble fibre (g/100 g)	Insoluble fibre(g/100 g)	Total Fibre (g/100 g)
Control	0.74	0.96	1.7
70% Sucrose	0.98	0.82	1.8
Apple pomace	1.48	1.22	2.7
Whey permeate	0.83	0.67	1.5
Oligofructose	1.6	<0.5	1.6
Polydextrose	1.6	<0.5	1.6

Highlights

- Sucrose was replaced by alternative sweeteners in a cake formulation.
- A total sugar reduction of 21-27% was achieved and cake structure was maintained.
- Addition of apple pomace negatively affected the volume and hardness of the cake.
- A sensory panel ranked the reduced sucrose cakes as acceptable.



Speific Volume (g/ml)
2.10
2.05
2.00
1.95
1.90
1.85
1.80
1.75
1.70
a
ab
b
ab
ab
ab
Control (100% sucrose)
70% Sucrose
Apple Pomace
Whey Permeate
Oligofructose
Polydextrose

Figure 1

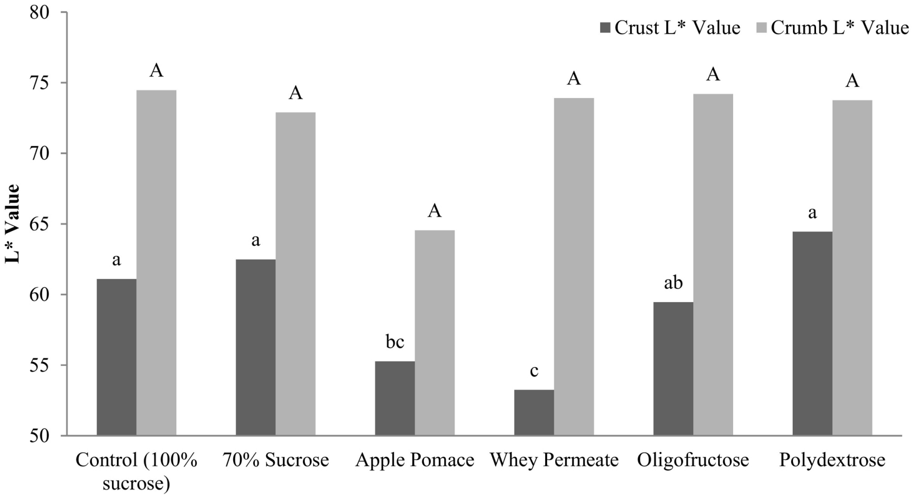
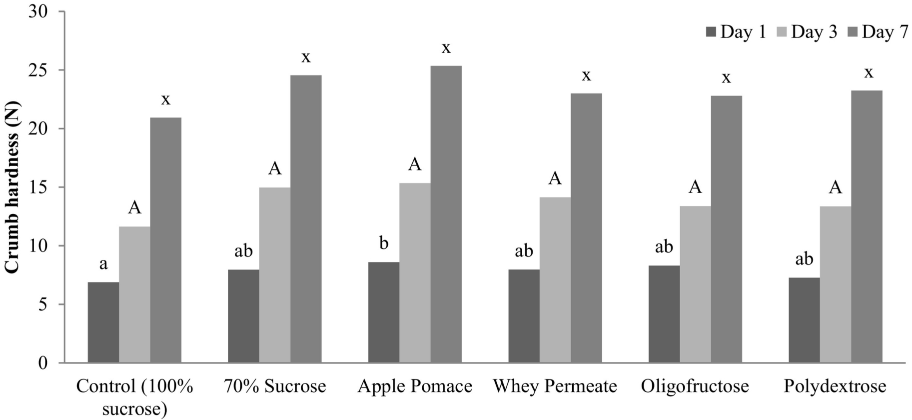

80
75
70
65
60
55
50
L* Value
Crust L* Value
Crumb L* Value
a
A
a
A
bc
A
c
A
ab
A
a
A
Control (100% sucrose)
70% Sucrose
Apple Pomace
Whey Permeate
Oligofructose
Polydextrose

Figure 2



Crumb hardness (N)
30
25
20
15
10
5
0
Day 1
Day 3
Day 7
a
A
x
ab
A
x
b
A
x
ab
A
x
ab
A
x
ab
A
x
Control (100% sucrose)
70% Sucrose
Apple Pomace
Whey Permeate
Oligofructose
Polydextrose

Figure 3

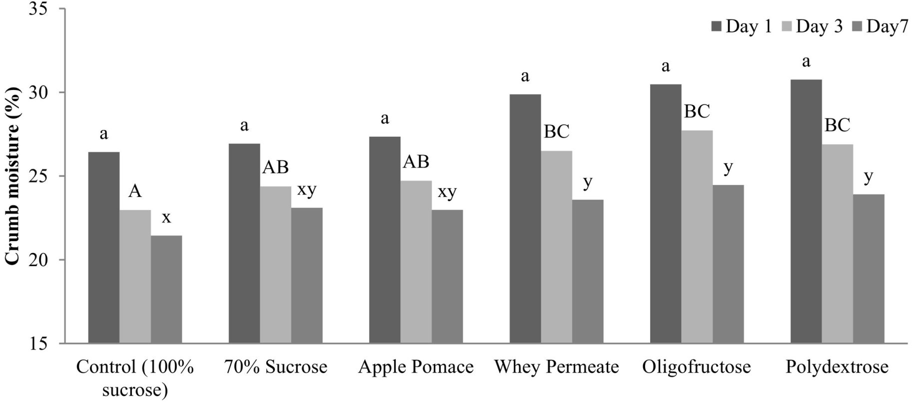

Crumb moisture (%)
35
30
25
20
15
Day 1
Day 3
Day7
a
A
x
a
AB
xy
a
AB
xy
a
BC
y
a
BC
y
a
BC
y
Control (100% sucrose)
70% Sucrose
Apple Pomace
Whey Permeate
Oligofructose
Polydextrose

Figure 4

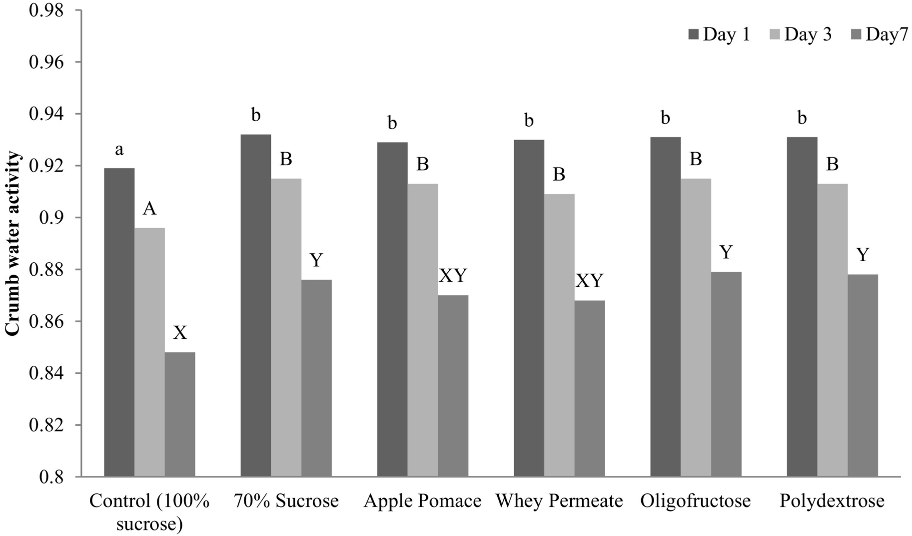

Crumb water activity
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
Day 1
Day 3
Day7
a
A
X
b
B
Y
b
B
XY
b
B
XY
b
B
Y
b
B
Y
Control (100% sucrose)
70% Sucrose
Apple Pomace
Whey Permeate
Oligofructose
Polydextrose

Figure 5

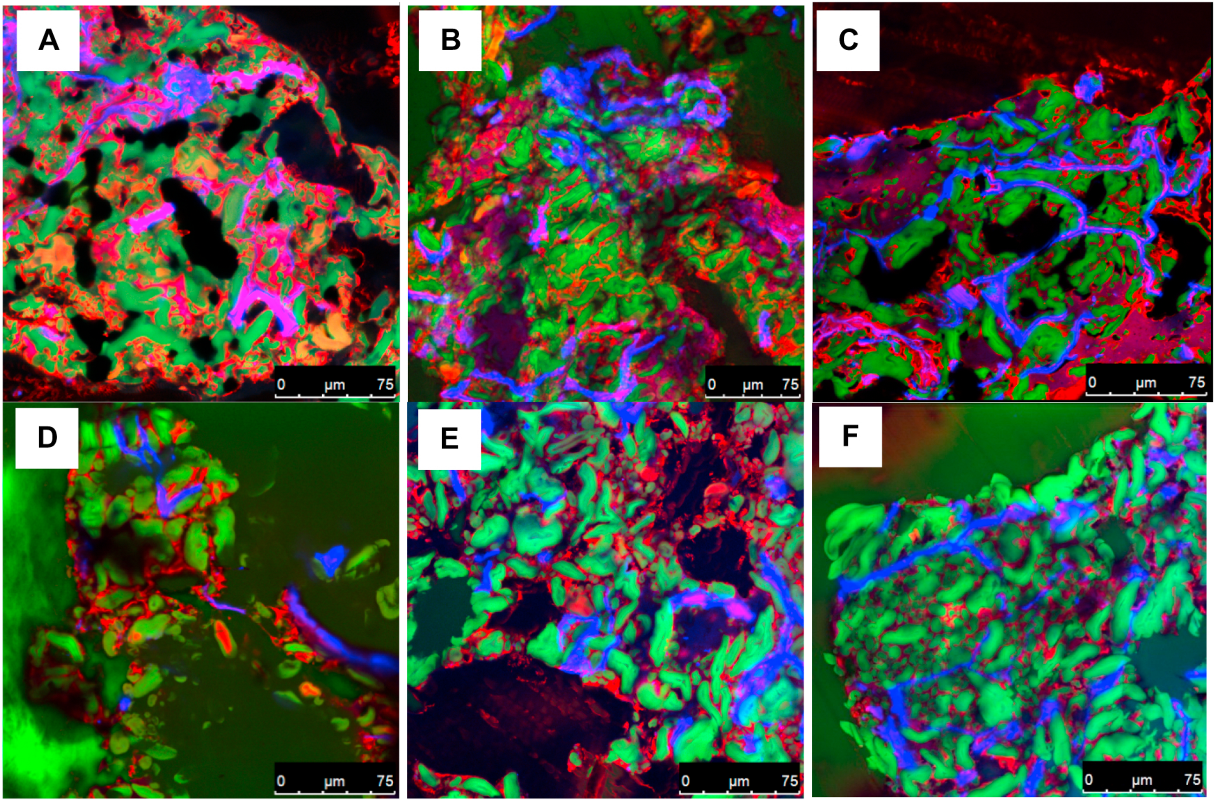


Figure 6

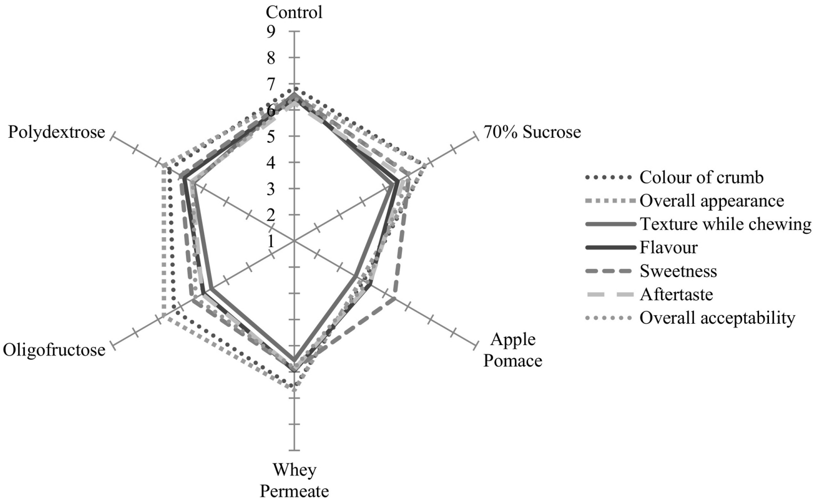

Control
9
8
7
6
5
4
3
2
1
70% Sucrose
Apple
Pomace
Whey
Permeate
Oligofructose
Polydextrose
Colour of crumb
Overall appearance
Texture while chewing
Flavour
Sweetness
Aftertaste
Overall acceptability

Figure 7